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TENTATIVE METHOD FOR MAKING RESISTIVITY MEASUREMENT OF DRILL CORES AND HAND SPECIMENS OF ROCKS AND ORES

BY

M. W. PULLEN

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This is the first of a series of papers dealing with the measurement of geophysical constants to aid in prospecting in the United States. These papers are being prepared by members of the various technical institutions in cooperation with the Bureau of Mines for the purpose of securing uniform and comparable data.

After a sufficient number of these papers have been secured and thoroughly discussed, a systematic program of measurement for classification purposes will receive full consideration.

It is hoped that these papers will receive careful study and suggestions from all interested in applied geophysics.

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TENTATIVE METHOD FOR MAKING RESISTIVITY MEASUREMENTS OF DRILL CORES AND HAND SPECIMENS OF ROCK AND ORES [1]

By M. W. Pullen[2]

Introduction

It is recognized that the determination of electrical resistivity of the earth within a given area may furnish information concerning the location of certain mineralized strata of economic importance. Present knowledge of the electrical resistivity of the various rock formations is almost nil, and the geophysicist who is detailed to make a survey of an area without any data as to the relative resistivity of the underlying rocks is greatly handicapped. Such surveys are usually made within areas known to contain mineral deposits to aid in locating desirable points for drilling. Usually these areas have been prospected by diamond drilling, and drill cores of the various rocks and ores are usually obtainable.

Were it possible to make resistivity tests in a laboratory of the drill cores or from pieces of the rocks and ore within an area before attempting a field survey, this would indicate not only the advisability for such a survey but would aid considerably in the interpretation of the results of such a survey. To be of most value a definite method should be used for all such tests, and as yet such a method has not been established.

This paper intends to present a tentative method and the results of tests of drill cores from the Mineville magnetite district and of hand specimens of serpentine and chromite.

Method Used for Hand Specimens

A specimen of each material, having roughly the same size and irregular shape with flat nearly parallel opposite faces, was obtained. The electrodes used were puddles of mercury 3.5 inches (8.9 centimeters) in diameter. The mercury in the lower electrode was confined in a dam of wax and the specimen set down upon it.

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1 The Bureau of Mines will welcome reprinting of this article, but requests that the following footnote acknowledgment be used: "Printed by permission of the Director, U. S. Bureau of Mines. (Not subject to copyright.)"

2 One of the consulting engineers, U. S. Bureau of Mines.

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The upper electrode was formed in a similar manner, the wax being built upon the specimen. Irregular readings indicated surface leakage of the measuring current, so a guard ring was arranged by making a second dam outside the upper electrode dam. The guard ring helped materially, and readings were at once more consistent; that is the galvanometer used gave steady instead of irregular deflections.

The connections for the tests are shown in Figure 1. It will be noted that the galvanometer was shunted and that a known resistance was used in the tests and calibration. The method of measurement is that of direct deflections, the known resistance being substituted for the unknown and adjusted so that the galvanometer gave equal deflections on each, the shunting resistance of the galvanometer being changed if necessary. Simple calculation then gives the value of the unknown resistance in terms of the known resistance.

Resistivity Measured with Direct Current

For the first tests, on serpentine, a single dry cell was used as a source of current and the readings taken rather quickly. Upon calibration it was found that the specimen showed a resistance of 25 megohms with the top electrode positive and 13 megohms with current reversed. It was certain that an error was involved, and as a first attempt at elimination the e.m.f. was increased by using two dry cells.

Readings were taken, and time was found to be an element in the result, as shown in Table 1.

Table 1.- Effect of time on resistivity

Polarity		Resistance,	Time,	
Top	Bottom	ohms	p.m.	Remarks: Serpentine
+	-	210,000	1:36	Reading on max. deflection of galvanometer
-	+	- - -	1:36	Battery promptly reversed; galv. off scale
-	+	504,000	1:39	
-	+	754,000	1:46	
-	+	1,039,000	1:53	
-	+	2,120,000	2:40	

The specimen of chromite was next prepared, and as a matter of course time was taken into account. The same two dry cells as above were used. The switch was closed and the set-up left for nearly 23 hours, then readings were taken with the results given in Table 2.

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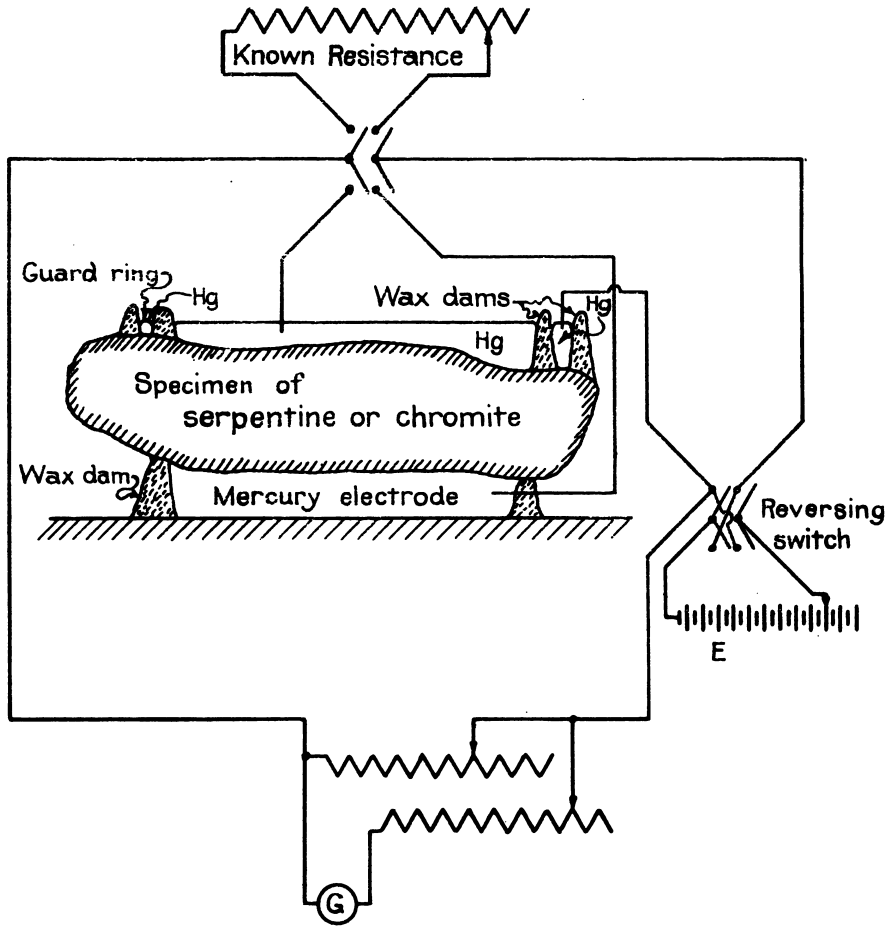

FIGURE 1.-Connections for continuous-current measurement

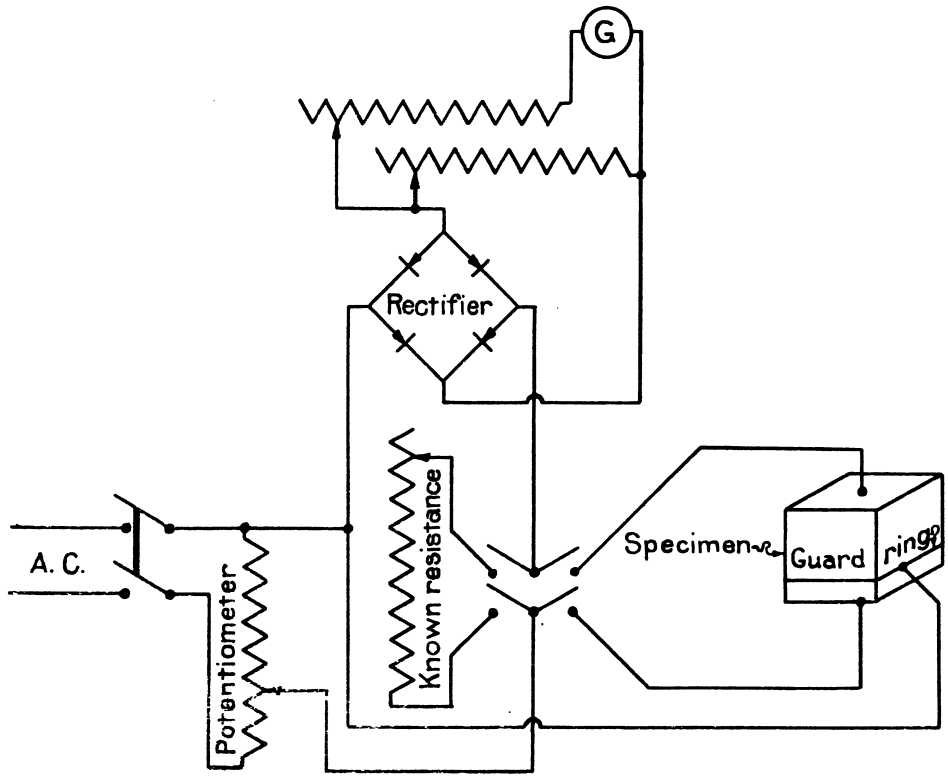

FIGURE 2.-Connections for alternating-current measurement

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Table 2.- Effect of time on resistivity

Polarity		Resistance,	Time,	
Top	Bottom	ohms	p.m.	Remarks: Serpentine
+	-	7,960,000	1:54	Current on 23 hours previously.
-	+	- - -	1:55	Reverse battery; galv. deflects of scale.
-	+	3,110,000	1:56	
-	+	3,620,000	2:01	
-	+	3,980,000	2:10	
-	+	4,630,000	2:40	
-	+	5,925,000	2:42	
-	+	6,150,000	3:30	
+	-	- - -	3:31	Reverse battery; galv. deflects off scale.
+	-	4,330,000	3:35	
+	-	5,800,000	4:00	

These results also show that time is a very considerable factor in the measurements and not to be neglected, yet the proper time to use is by no means evident.

Since the two specimens above were not of such shape as to render calculation of their resistivities practical, a piece of serpentine was obtained from which a cube was cut, measuring nearly 5 inches (12.7 centimeters) on edge. For electrodes the bottom of the block was set in a pool of mercury, while a wooden frame at the top confined the mercury for the upper electrode. A guard ring was arranged by placing grooved wood strips around the block near its base. This made a very satisfactory arrangement. The connections used were those of Figure 1, and again the material showed a resistance that varied with time over several hours, as well as having a dependence on the previous polarity (see Table 1). For instance, the e.m.f. (two dry cells) was left on over night and the galvanometer deflection found to be 16.4 cm. the next morning. The battery was reversed and the galvanometer promptly deflected off scale, but gave a reading of 22.0 centimeters an hour and twenty minutes later.

A specimen of the chromite was prepared of a shape that would render calculation of its specific resistance convenient. Electrodes were also prepared. In this test wax was used to confine the mercury, as the surface of the ore was too irregular for the use of wooden strips. Substantially the same behavior was observed under the application of the electric current as in the tests of serpentine above.

In the work already outlined somewhat different results were found in the use of one and then two dry cells, so in the hope that better results might be obtained various values of voltage were applied to the serpentine specimen and the specific resistance calculated for each voltage. Time was allowed for the galvanometer to reach a substantially constant reading, as indicated in the results shown in Table 3.

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Table 3.- Effect of d.c. voltage on resistivity

E.m.f. volts	Time, minutes	Specific resistance, megohm - cm. serpentine	Temp., 0°C.
2.71	5.0	25.75	26.0
25.0	5.0	16.63	
49.5	4.0	11.15	
74.5	4.0	10.93	
98.7	5.0	10.71	
122.0	2.0	10.20	
145.0	2.0	10.18	
167.5	2.0	9.69	
190.9	5.0	9.40	27.0
214.1	5.0	9.23	
237.0	5.0	9.00	27.5
259.5	5.0	8.72	
282.0	5.0	8.34	28.0

In this table it will be noted that the initial reading was taken after five minutes electrification, and in view of the previous results the specimen could have been expected to show even higher values for a longer time. However the galvanometer motion, if any, was so slow as to be unnoticeable over a short period, and the value given is that which would be obtained by ordinary experimental procedure. In the balance of the table the readings were taken after the elapsed times as noted. No attempt was made to short-circuit the condenser made up of serpentine dielectric and mercury electrodes between readings as here given. This was tried on another occasion without any material change in the final result obtained. A very short time was required to change the value of the applied voltage, it being done by shifting connections on a bank of radio B batteries. Higher voltages than 282 were not attempted because the galvanometer tended to deflect due to leakage currents. Indeed, on a day of high humidity it was impossible to work at all with the apparatus available.

The data given indicate that the material tested showed very marked effects from dielectric absorption and polarization. The polarization shows up much more on the lower voltages than the higher values. However, a complete discussion of these effects is not possible in this paper, and for that reason the apparent specific resistances as obtained are given.

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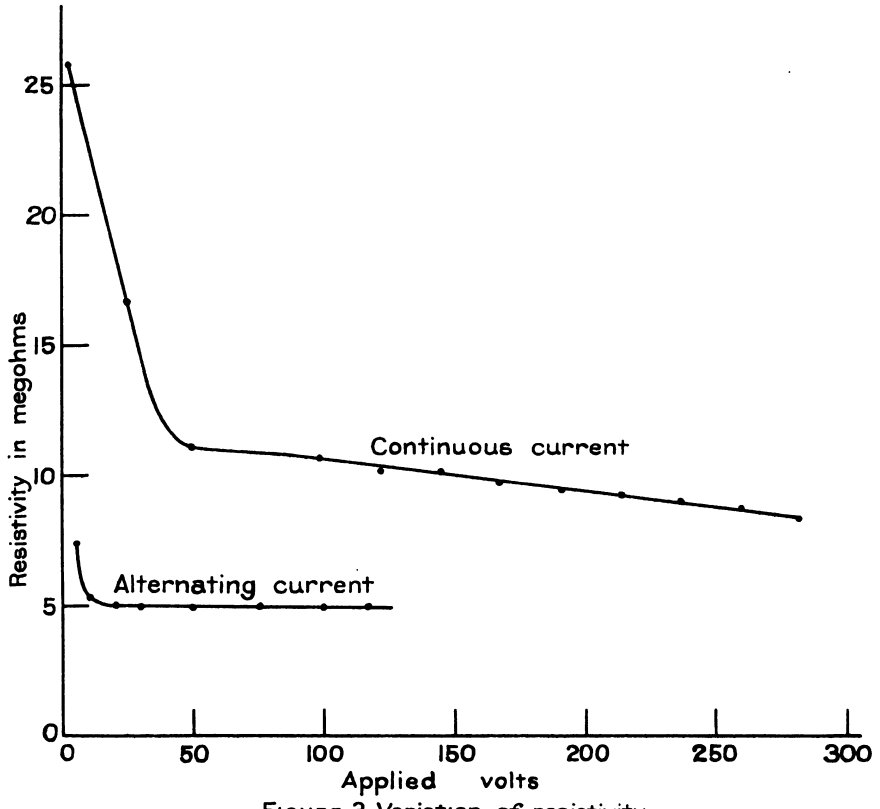

FIGURE 3.—Variation of resistivity of serpentine with applied voltage

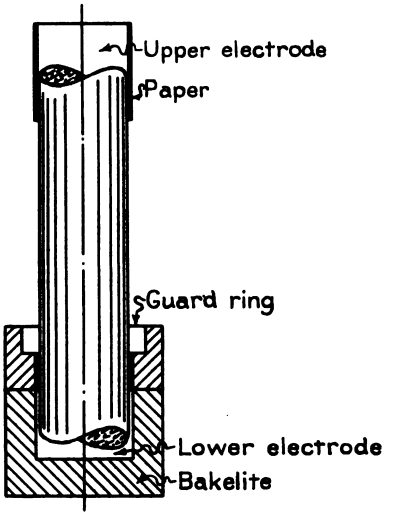

FIGURE 5.—Arrangement for mercury electrodes with diamond-drill core

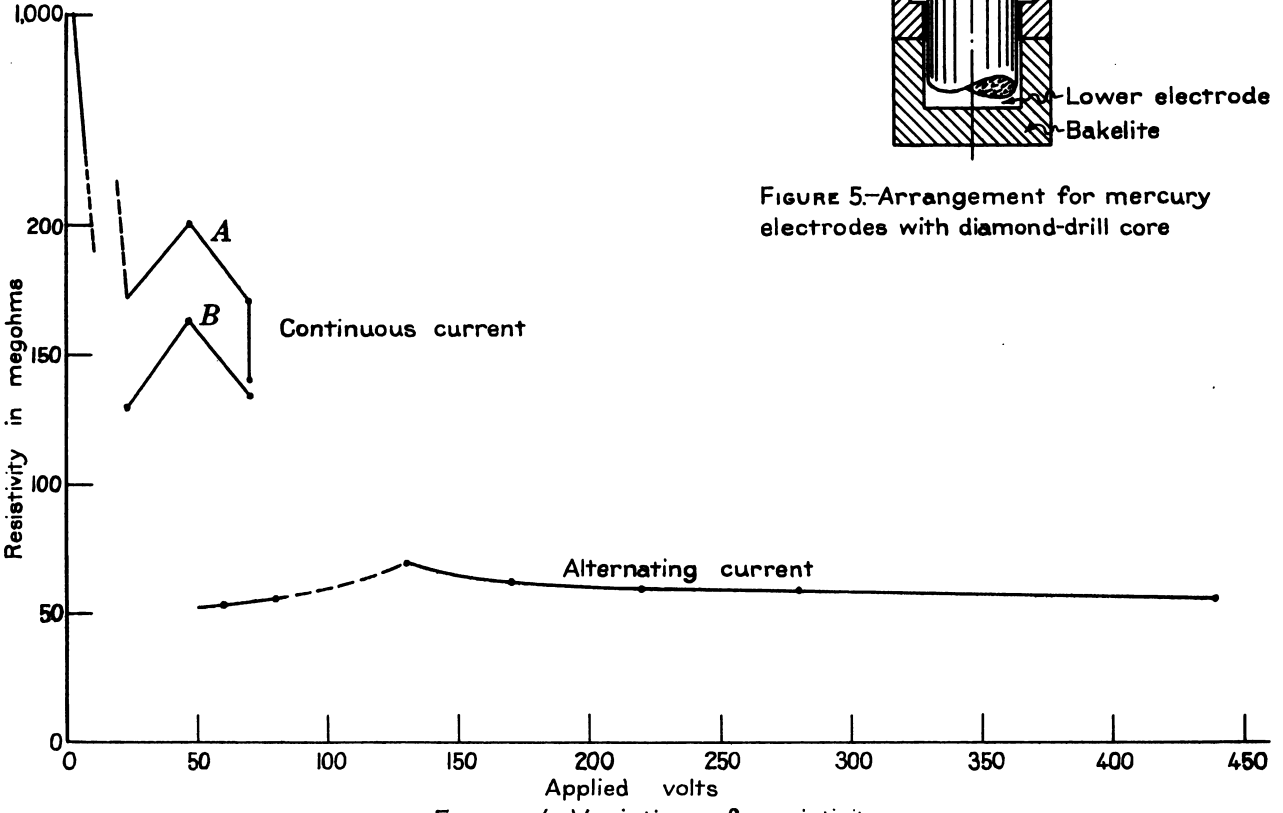

FIGURE 4.—Variation of resistivity of chromite with applied voltage

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Resistivity Measured with Alternating Current

Since reversal of polarity on the specimen gave erratic readings with the continuous current, alternating current at 60 cycles was tried and the specific resistance at various voltages determined. In this case the current through the specimen was rectified with Grondahl copper oxide rectifier so that an ordinary galvanometer might be used. Connections for this test are shown schematically in Figure 2. The resistance was determined by switching from the specimen circuit to that of known resistance, which was adjusted so that the galvanometer gave the same deflection on each. A quick change-over switch was used and several checks taken at each value of voltage used. This procedure eliminates any probability of error in rectification in the rectifier, and has the advantage of giving as nearly a direct reading as can be obtained with simple apparatus. The scheme works surprisingly well, and the results obtained on the serpentine specimen are given in Table 4.

Table 4.- Effect of a.c. voltage on resistivity

E.m.f., volts	Specific resistance, megohm - cm. serpentine
5.0	7.35
10.0	5.36
20.0	5.06
30.0	4.98
50.0	4.95
75.0	4.93
100.0	4.39
117.0	4.88

Here it will be noted that with alternating current the specific resistance, as measured, is less than half the value as measured with continuous current for values above 50 volts and at lower values of voltage the difference is even greater. Further, it is noticed that the value of specific resistance as obtained becomes practically constant at a comparatively low voltage, which is not the case with continuous current.

The two curves in Figure 3, showing the relation between resistivity and voltage for the serpentine block as measured, indicate that whereas the values for continuous current have not reached a constant value for the highest voltage used those for alternating current are practically constant at and beyond 30 volts. To put the situation in another way, since the block stands 12.45 centimeters, an e.m.f. of 2.4 volts per centimeter of length gives a value of resistance which is substantially correct, whereas with continuous current a value ten times as great gives a result that is doubtful and subject to variation with time of application.

The trend of the curve for continuous current is such as to lead on to surmise that had the applied voltage been high enough the resistivity value obtained would be the same as for alternating current. At the time the measurements were made the truth of this surmise could not be tested, having the safety of the apparatus available in mind.

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Measurement of the resistivity of the chromite specimen was by no means as simple as the measurement of the serpentine because of its higher value. Direct substitution of the known for the unknown resistance could not be made, for so high a resistance was not available. However the values given were checked carefully and should prove of value. Table 5 gives the data on the continuous current measurements and it will be noted that the time of application of voltage is given. The chromite shows the effect of polarization and dielectric absorption to a greater extent than serpentine, hence the values given are reliable only for the times stated and thus are subject to variation under other conditions.

Table 5.- Resistivity measurement of chromite

E.m.f., volts	Specific resistance, megohm - cm.	Temp., °C.	Remarks: Chromite
2.7	1,008.0	22.0	1 hr. 15 min; value still changing.
23.5	129.0	22.0	3 minutes
	171.6	22.0	40 minutes later
47.0	163.0	25.4	3 minutes
	201.0	25.4	6 hours later
	134.6	25.4	1 min., following value just above at 47.0 v., 6 hrs.
70.0	139.5	25.4	2 hours, 14 minutes later
	170.7	24.0	24 hours

Temperature undoubtedly has some effect, but the changes due to this cause are small indeed compared to that of time or voltage.

Alternating-current tests of the same sample of chromite as was used with the continuous current give values of specific resistance varying with applied voltage, but no worse than in the case of serpentine. Moreover the tests were difficult to make because of the very small currents involved, even at rather high voltages. The results given, Table 6, have been checked several times and are thought to be reasonably accurate. Readings below 60 volts were uncertain and have been discarded.

Table 6.- Resistivity of chromite

E.m.f., volts	Specific resistance, megohm - cm.	Temp., °C.	Remarks: Chromite
60	52.5	30.0	Connections as in Figure 2.
80	54.8	30.0	Do.
130	68.6	26.5	Transformer and potentiometer used
170	61.2	26.8	Volts read on primary and multiplied
220	58.3	27.0	By the ratio of transformation
280	58.8	27.0	Do.
440	55.2	27.5	Do.

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Here again, as with serpentine, the resistivities as measured with alternating current are much lower than with continuous current. Moreover, once the set-up is made the values are more quickly determined, since the alternating current eliminates the time factor, and one has only to wait till the galvanometer comes to rest, a matter of a few seconds at most. The voltages used on the chromite do not cover exactly the same range, though there is enough overlap to give an excellent idea of what is going on. This is seen better in the curves plotted in Figure 4. In this figure the points for continuous current are erratic and there seems no reasonably short method of getting more consistant results. The difference in values of resistivity shown in points A and B are due to different times of application of the test voltage (see Table 4). The values of resistivity on alternating current are not quite consistent as between points at 60 and 80 volts and values above 130 volts. Current for the lower values of voltage was taken from the lighting mains as shown in Figure 2, whereas those for higher values were obtained by stepping up the voltage with a potential transformer run inverted and hence not in a proper working condition. The readings at the higher voltages are, however, consistent among themselves and show the same trend as in the case of serpentine tested on alternating current.

Method Used for Diamond-Drill Cores

Attention was now turned to the diamond-drill cores, of which some 140,000 feet were available for testing. The cores are of various lengths, up to over 2 feet. As a large number of measurements had to be made, two blocks of bakelite were turned up in such shape as to hold the mercury for the lower electrode and the guard ring. A paper collar confined the mercury for the upper electrode. Figure 5 shows a sectional view of the arrangement and Figure 2 the connections. The core diameter is about 7/8 inch (2.22 centimeters); and lengths up to about 7 centimeters were used, although if possible shorter lengths were preferred, as giving higher values of volts per centimeter.

From an electrical standpoint it was found that the cores fell, roughly, into three classes: (1) Those of such low resistance as to be measurable by direct comparison with a known resistance, (2) those of such high resistance that only an estimate could be made of the probable values, and (3) those in a mid-region, too high for direct comparison, yet measurable by the "method of direct deflections," a standard method in continuous current work, but here used with alternating current and the Grondahl rectifier. In this group the readings were consistent, and while it is not claimed that they are perfect the values are reasonable. The applied voltage used was 90 volts, under which the galvanometer would, on the highest resistance specimens, barely deflect. On the other hand, for the low resistances almost any desired deflection could be obtained by shunting the galvanometer. The minimum voltage gradient was thus not less than about 12 volts per centimeter.

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Resistivity Measurement of Drill Cores at Various Depths

The ground resistivity of the area from which some of the cores had been taken had been measured by Dr. F. W. Lee[3] so in order to give point to further tests, measurements were made on the resistivity of the cores from the same locality. The records give the depths of geological data on the cores and were used in determining which cores should be tested.

Rather than tabulate the mass of data obtained, the results have been plotted and are shown in Figures 6, 7, and 8. In each instance the figure shows the geological formations and the depths at which they occur. Alongside is shown the curve of resistivity. The curve is not continuous, as only a few cores in each formation were tested. For values that were too great for accurate measurement the points are shown as solid circles and the curve dotted to them.

Examination of the curves shows that the values of resistivity of a given material differ among themselves. When the measurements were made it was observed that in many cases a core stated to be a certain mineral had a different resistivity from a core denominated with the same name even though from the same approximate depth. Superficial examination showed that the cores looked much alike but were not of exactly the same appearance. That they were different even though named alike is evident from the resistivity values. The "ore" mined by the company is magnetite, and this is what is meant by the term "ore" in the drill records reproduced here.

Comparison of the three curves given shows a striking similarity between them. As the ore bed is approached from above the resistivity is found to be very high, then it drops rapidly to a low value for the mineral just above the ore. The ore itself on test shows a resistivity that is higher than the rock above it unless the ore is very rich. In all cases the cores of the ore had been split for analysis, thus making measurements of resistivity difficult and uncertain. The resistivity of the ore is high, as the magnetite is segregated in discrete particles embedded in rock of high resistance. Only a very rich ore shows a low resistance, although the rock just above the ore has a low resistance. Below the ore bed the resistivity again raises to a high value, after a short distance of low-resistivity mineral.

In the curves shown there are apparently some exceptions to the observation that the ore bed has just above it a high, then a low, followed again by a high resistivity. However, comparison of the curves shows that the exceptions are only apparent but for the depths, 600 to 650 feet in Figure 7, hole No. 345. In all other cases the low resistivity persists for only a very short distance.

Effect of Moisture on Resistivity of Drill Cores

It is to be noted that the data on the diamond-drill cores were taken with the cores dry as stored in the core shed. They were laid in boxes open to the air and had been thus for several years. Consequently, it was desirable to determine the effect of moisture on the resistivity. To this end cores were selected from hole No. 348 and soaked 24 hours in mine water. The cores were then wiped off and allowed to surface dry for one hour and then their resistivity measured. Table 7 gives the results of the test.

3 Lee, F. W., Measuring the Variation of Ground Resistivity with a Megger: Tech. Paper 440, Bureau of Mines, 1928, 16 pp.

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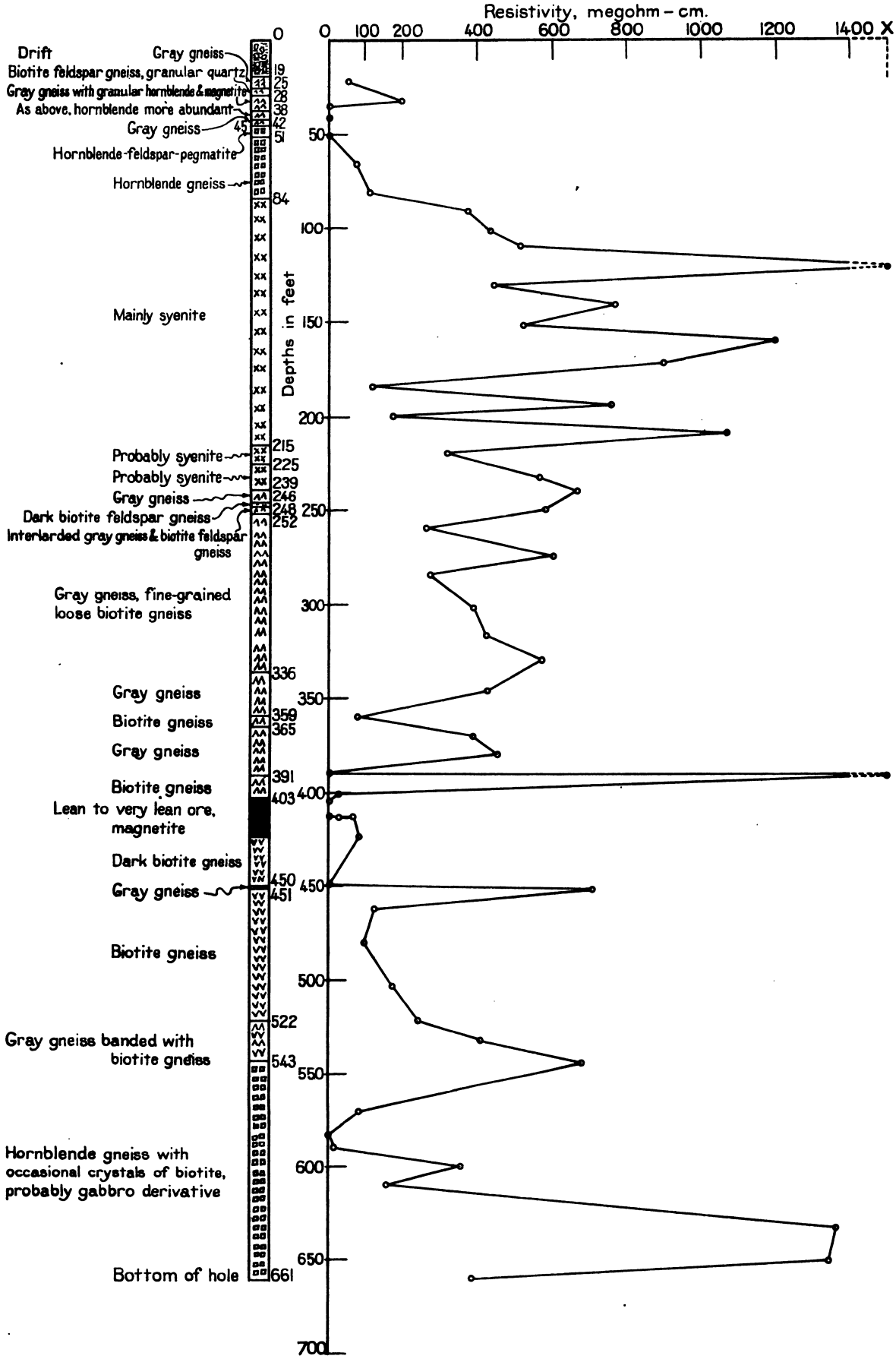

FIGURE 6.—Drill hole 338. Resistivities of diamond-drill cores for depths shown

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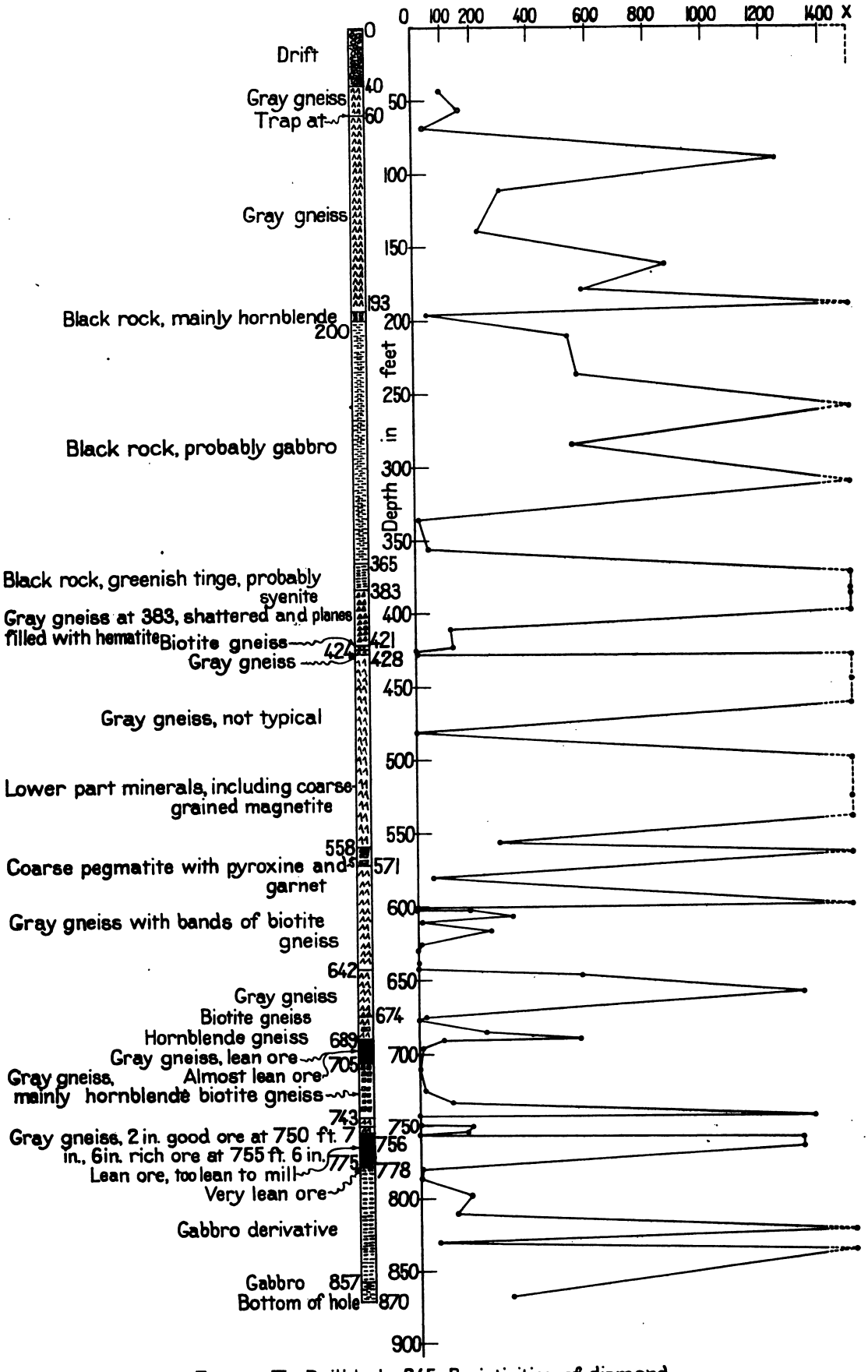

FIGURE 7.—Drill hole 345. Resistivities of diamond-drill cores for depths shown

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Table 7.- Resistivity at various depths

Hole 348 core Test No.	Depth, feet	Resistivity, megohm - cm.	
		Dry	Wet
1	32	1/2,730	3.65
3	45	37.3	1.216
5	71½	.503	.279
10	96	.355	.325
13	112¾	47.3	1.203
20	201	1,123	342.0
23	300	1/3,480	1/2,830
29	377	1/4,075	1/2,310
33	420½	.928	.848
37	499	1/2,250	148.0
42	602½	1/3,860	91.0
46	674	3.32	.603
52	748	1.293	.772
57	815	222.5	114.2
63	915	65.75	7.78

1/ Estimated value.

In every case the soaking in mine water reduced the resistivity of the core tested. The relative change among the cores varies very widely, and apparently upsets the observations made for the dry cores. However, if the values of resistivity wet are noted on the curve of Figure 8 it will be found that these observations still hold good. The points for resistivity wet are shown in the larger circles joined by the heavy dashed lines. Continuous current methods of measuring the resistivity of minerals are uncertain in their results.

An alternating-current method of making these measurements is described. This method gives consistent results of reasonable reliability and is easily worked.

A large number of diamond-drill cores were tested for resistivity, and the result is shown graphically. From these curves it is evident that with a method of determining the variation of ground resistivity at various depths it should be possible to identify some of the geological formations at those depths.

Conclusions

1. Surface leakages of current must be reduced for reliable resistivity measurements.

2. Resistivity measurement is associated with electrical polarization, and the factor of time therefore enters as an element in its determination.

3. The rate of polarization differs in various rocks.

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4. There is a variation of resistivity as a function of applied voltage and frequency.

5. Because of low values of measured current, d. c. instruments must be used in a.c. circuits when measuring a.c. resistivity.

6. There is a difference between a.c. and d.c. resistivity.

7. A definite method is proposed for preparing drill cores and hand specimens for resistivity measurements.

8. Rock specimens of the same classification from different horizons of a drill core may show a wide variation of resistivity due to the latitude in the rock classification.

9. Water content may greatly alter the resistivity of materials.

10. Resistivity of a conducting ore body may be high, if the particles of ore are disseminated.

Remarks

The main object in presenting these data is to invite discussion upon electrical resistivity measurement methods in order to establish, if possible, a uniform procedure in making resistivity tests. It is also important to take up the discussion of results in order to adopt a system of rock resistivity classification.

It is hoped that all working in this field will pool some of their information and experience and thereby avoid wasteful repetition of expenditures. Much work has been done upon resistivity measurements, but the details of measurement are generally omitted and therefore render the values unreliable. Also, much information of this kind has been transcribed from foreign investigations and is not sufficiently delineated geologically to be of much practical value.

There is some evidence that the resistivity of the samples measured is a function of the applied voltage gradient to the sample. This voltage gradient from applied potentials to the ground is of the order of millivolts and under. Because high-resistivity material was measured at a high voltage and would therefore introduce relative errors a method must be devised to obviate this difficulty. The frequencies used for resistivity measurement are of the order which allow only conduction currents to flow. High frequencies introduce displacement currents as well and would further complicate the problem.

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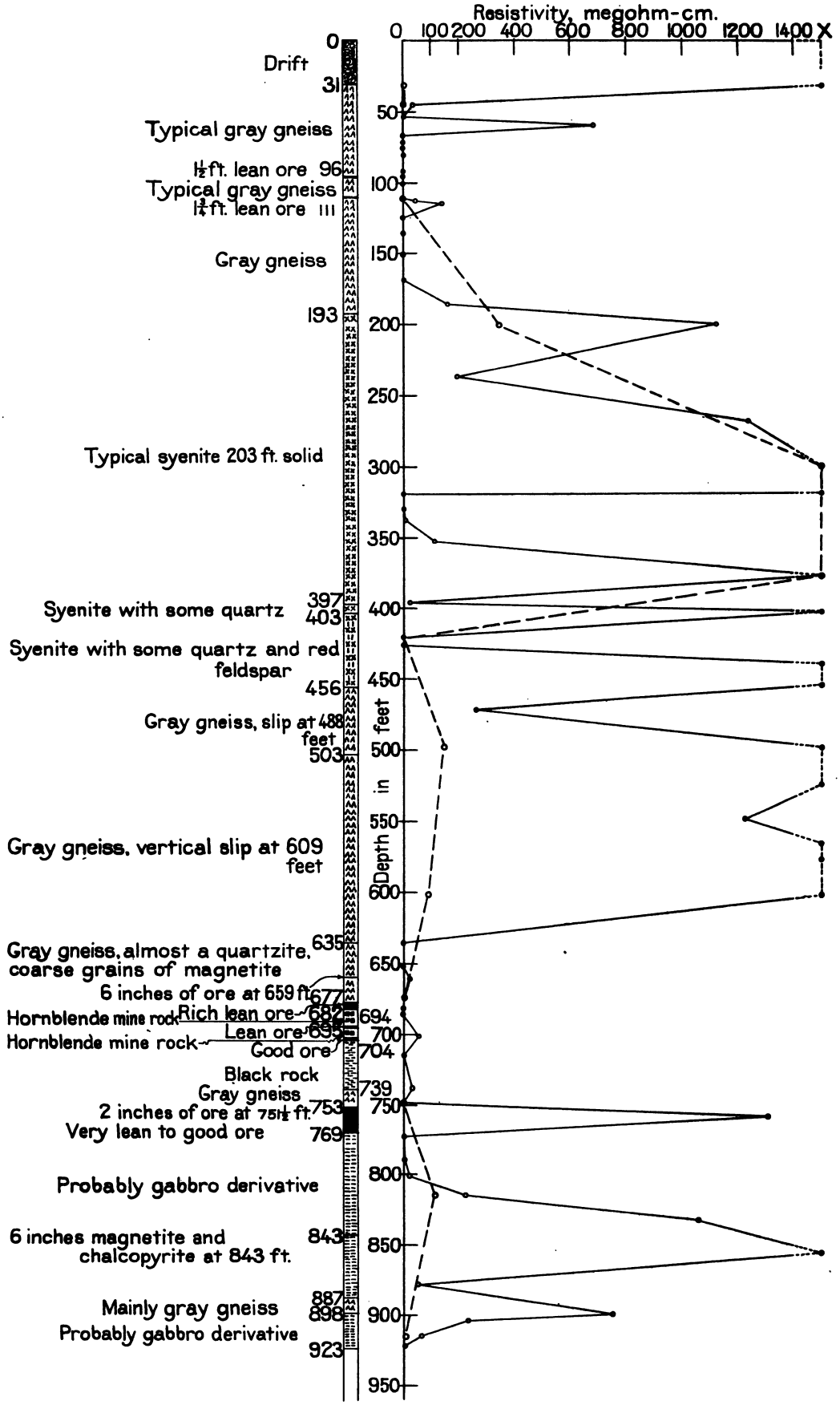

FIGURE 8.—Drill hole 348. Resistivities of diamond-drill cores for depths shown. Dashed line shows resistivities of wet cores

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